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NEAR FIELD SMALL EARTHQUAKE STRONG MOTION STUDIES

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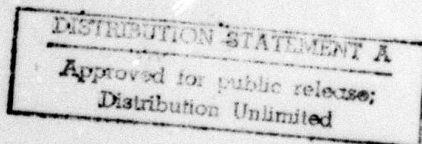
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ABSTRACT

The objective of the Joint Experiment on Earthquake Source Spectra is to improve our ability to distinguish between the explosive and tectonic energy releases in the magnitude range $3 \leq M \leq 5$. Recording the near-field strong ground motion will help in the more accurate determinations of the earthquake source time function and thus will improve the reliability of the near- and far-field spectra which are still the basic tools in detection work.

$3 \leq M \leq 5$

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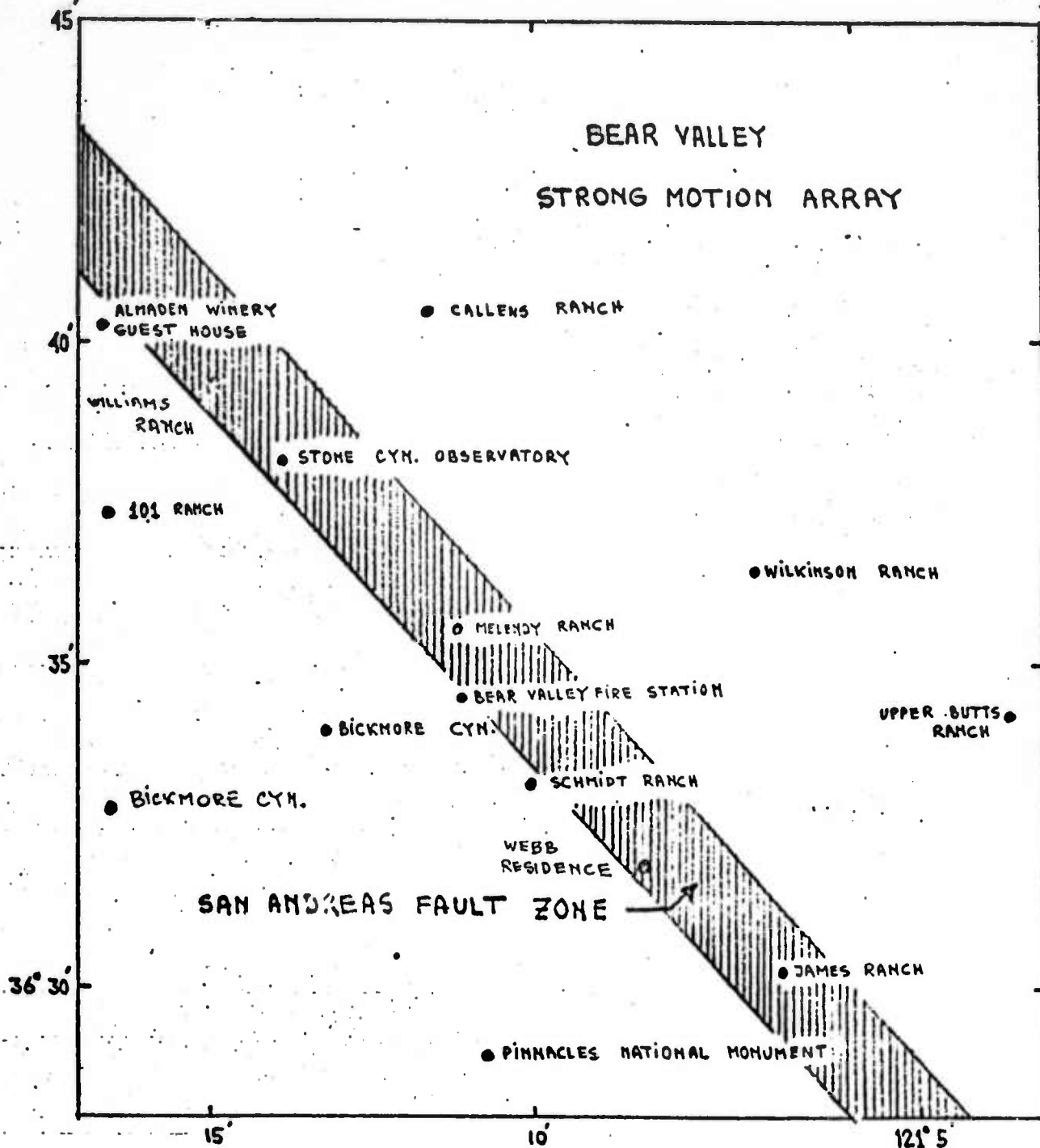
Summary

To provide continuity of all Semi-Annual Technical Reports through an accretion process, the following text includes all the details presented in the previous reports. A summary of the most recent results has been inserted in the previous text where appropriate.

The objective of this research has been to improve our ability to distinguish between the explosive and tectonic energy releases in the magnitude range $3 \leq M \leq 5$. This work will help in the more accurate determinations of the earthquake source time function and thus will improve the reliability of the near- and far-field spectra which are still the basic tools in detection work.

On September 29, 1972 the Earthquake Engineering Research Laboratory completed first installations of 12 strong-motion stations in Bear Valley, California. The elliptically shaped array (Fig. 1) is centered along the San Andreas Fault some 30 km southeast of Hollister, California.

From the records obtained by the network, the near-field accelerations, velocities, and displacements of ground will be obtained. By fitting theoretical spectra to these observations, the effective stress and other source parameters will be derived. The strong-motion



- TRIAXIAL STRONG MOTION ACCELEROGRAPH (SMA-1) EQUIPPED WITH A WWVB RECEIVER (CS-60).

Figure 1

network will provide a means to observe the flux of seismic energy away from the source and to study the detailed nature of the pattern of energy release. These measurements will be compared to the far-field measurements obtained by other study groups in this program and the effects of the path on seismic waves will thus be determined. In this way the accuracy of information desired from distant stations can be critically examined, tested, and complemented. In addition, the strong-motion network will furnish important clues to the rupture velocity, one of the most poorly known source parameters.

The data from five strong-motion accelerograph stations centered above and surrounding the fault have been used to develop an approximate three-dimensional dislocation model for the San Fernando earthquake $M_L = 6.4$ (Figure 2) (Trifunac, 1974). In the resulting model the dislocation originates near the instrumentally determined epicenter at a depth of 9.2 km and then propagates southwards and upwards with a velocity of 2 km/sec. Calculated dislocation amplitudes of about 10 m in the hypocentral region have been found to decay to about 1 m towards the center of the fault and then build up again to about 6 m just before the fault intersects the ground surface in the San Fernando Valley. The assumed fault area of 130 km^2 and the assumed rigidity $\mu = 3 \times 10^{11} \text{ dyne/cm}^2$ give a moment $M_0 = 1.53 \times 10^{26} \text{ dyne-cm}$. This study indicates that with several strong-motion accelerographs suitably located in the epicentral region it is possible to find a detailed kinematic faulting process.

Recordings from five strong-motion accelerograph stations have been used to derive a three-dimensional dislocation model for the

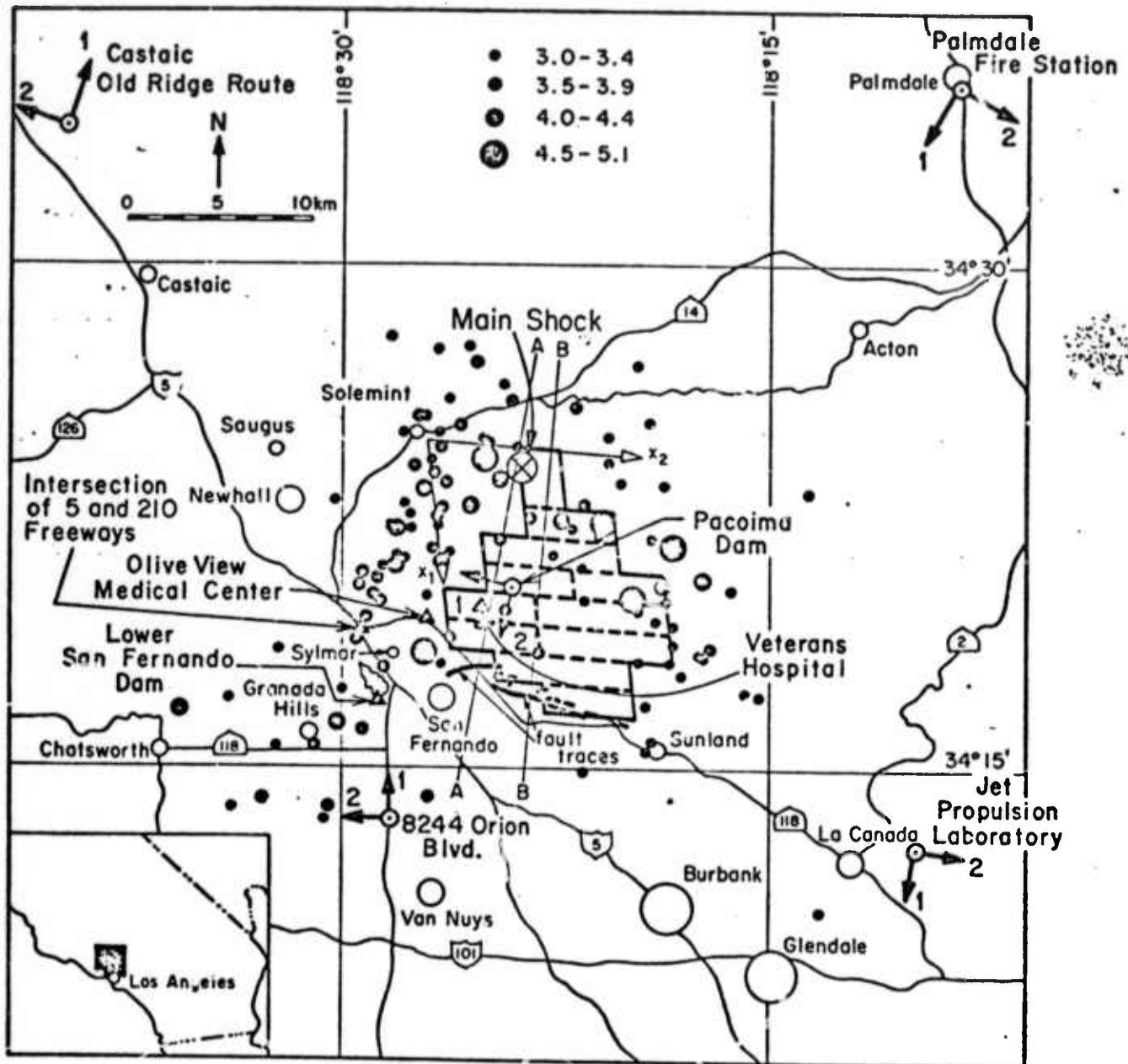


Figure 2

Parkfield Earthquake, $M_L = 5.8$ (Trifunac and Udawadia, 1974). The model consists of a buried fault which extends from a depth of 3 km to a depth of 9 km below the ground surface (Figure 3). It appears from the analysis, which considers various fault lengths, that the zone of significant faulting was the twenty kilometer long northwestern section of the fault. The rupture velocity has been found to be between 2.4 and 2.5 km/sec and the dislocation amplitudes have been found to be about 120 cm. There have been comparisons made of the model results with geodetic data on static deformations and creep measurements following the event. In contrast with several other source mechanism studies of the Parkfield event, this model yields a picture which appears to be very consistent with both the dynamic strong motion measurements as well as the available geodetic and creep data.

The Bear Valley, California, Earthquake of June 22, 1973 has been recorded at 10 strong motion stations of the Bear Valley array. Five stations surrounding the epicenter have been selected for further study and are shown in Figure 4. They surround the epicenter and provide adequate coverage for detailed source mechanism study. Preliminary work based on the three dimensional Haskell's (1969) model has indicated that this earthquake could be described by a rectangular fault $\frac{1}{2}$ by $\frac{1}{2}$ kilometers and at a depth of 10 km. A right-lateral fault could be characterized by an average dislocation of about 1 m and dislocation velocity of 3.0 km/yr.

ARRAY MAP SHOWING LOCATIONS OF ACCELEROGRAPHS, SEISMOSCOPES, AND FAULT ZONE

Parkfield Earthquake

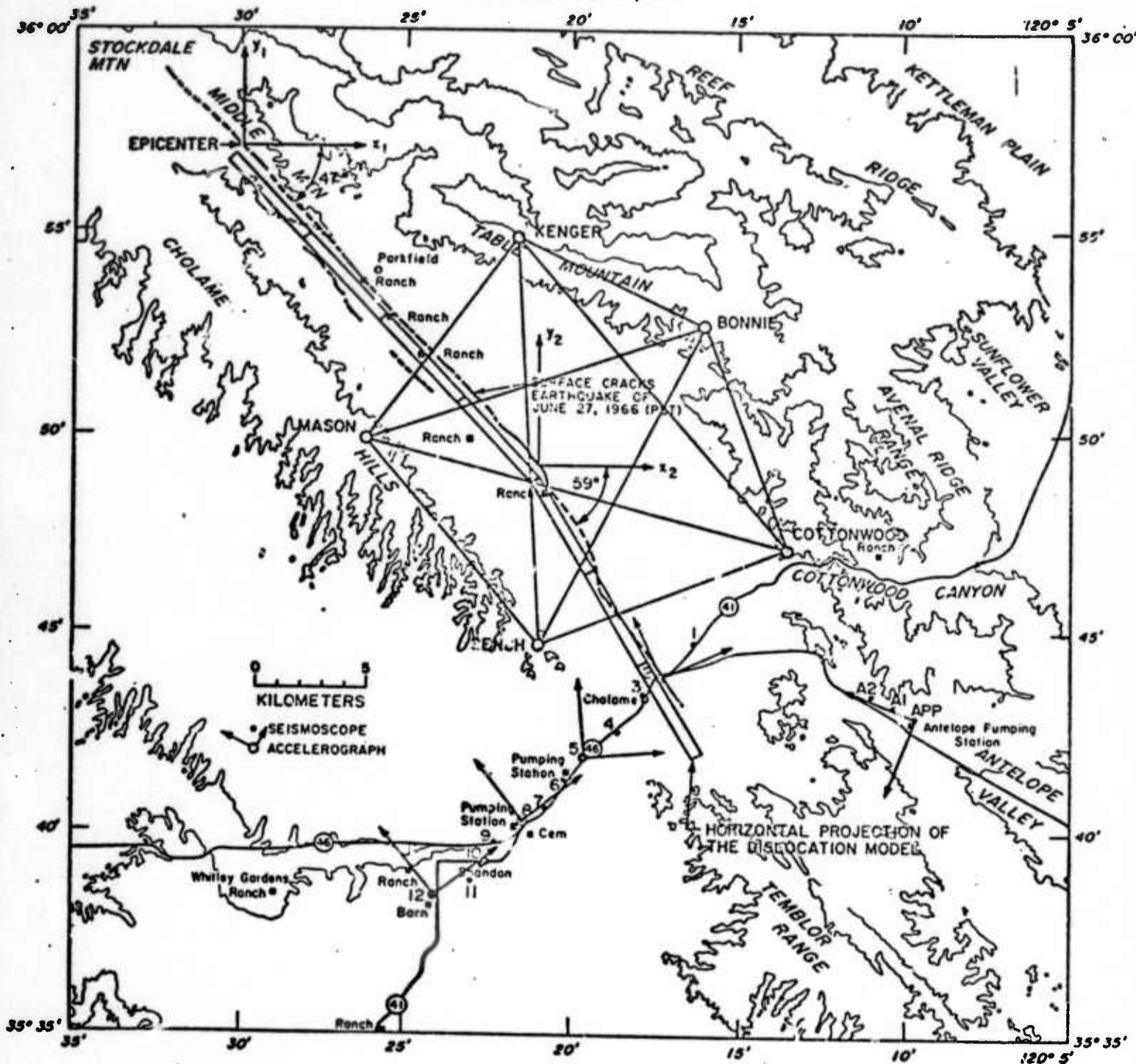


Figure 3

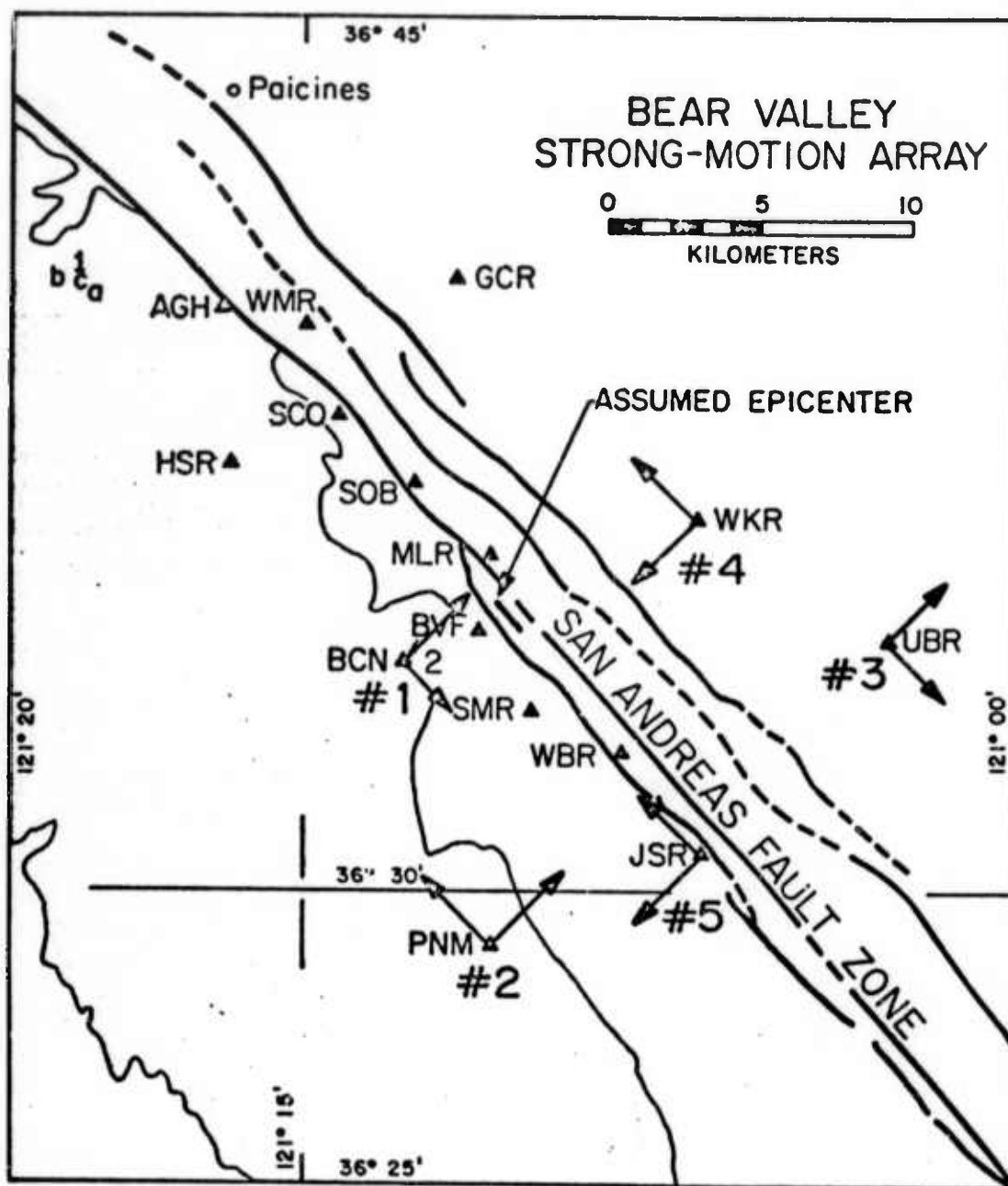


Figure 4

We are currently working on the spectral analysis of these five strong motion records to estimate the source dimensions from the spectra of P- and S-waves and to compare those with the results obtained from the three dimensional dislocation model studies. In this work five trial values for the attenuation constant $Q = 50, 100, 200, 300,$ and 500 have been examined. Preliminary results indicate that the eastern and southern stations (WKR, UBR, JSR) may be characterized by low Q (50 to 100) while the western stations (BCN and PNM) may be characterized by higher values of Q (100 to 300) for high frequency waves ($f > 10$ cps). The average source radius which results from spectral analysis is equal to 0.32 ± 0.10 km and the average dislocation and seismic moment range from 1 to 2 m and 1 to 2×10^{23} dyne-cm.

Experimental Program and Major Accomplishments

Nine field trips were made. During the first trip (26-29 July 1972) the Bear Valley area was explored and the tentative sites for strong-motion stations were selected. During the second trip (18-29 September 1972) twelve strong-motion stations were installed and have been operating since 29 September 1972). A typical station consists of one triaxial strong-motion accelerograph (SMA-1 type), manufactured by Kinemetrics, Inc., and a WWVB receiver providing the absolute time. The SMA-1 accelerograph provides accurate information about the strong-motion acceleration in the frequency range between 0.06 and 25 cps. It is expected that an earthquake of magnitude ≥ 4 occurring in the middle of the array will trigger all instruments.

During the third field trip (6-9 January 1973) stations Bickmore Canyon, Pinnacles National Monument, Schmidt Ranch, James Ranch, Stone Canyon Observatory, Bear Valley Fire Station, Almaden Guest House, and Callens' Ranch (Figure 1) were revisited for routine checkup and maintenance work. Weather conditions did not permit access to the four stations: Melendy Ranch, 101 Ranch, Wilkinson Ranch, and Butts Ranch.

During the fourth field trip (16-23 June 1973) all stations of the array were revisited for routine checkup and maintenance work; including the four stations: Melendy Ranch, 101 Ranch, Wilkinson Ranch, and Butts Ranch that could not be inspected during the third field trip because of poor weather conditions. Newly designed loop antennas were fitted to all stations because the original design did not appear to be fully water proof.

During the fifth trip (11-18 September 1973) all stations were revisited and serviced. The acceleration records from all stations, excluding Stone Canyon Observatory and Almaden Winery Guest House, were collected. Accelerograph at Stone Canyon Observatory site was moved to a new, nearby location to improve the noisy WWVB radio signal. New stations at Webb residence and Williams Ranch were installed.

During the sixth trip (10-17 December 1973) all stations were revisited and serviced. The fifteenth station was installed in the Bickmore Canyon.

During the eighth and ninth field trips during 22-26 June 1974 and 10-15 December 1974 all stations were serviced. At several stations (AGH, JSR, MLR, PNM and SCO) SMA-1-CS-60-P system

was replaced by the new SMA-1 with WWVB radio housed inside the accelerograph housing. Table I summarizes the earthquake records obtained during 1974.

Review of the Existing Data

The understanding of the detailed nature of spatial and temporal behavior of earthquake and explosion source mechanisms seems to us to be the key for the full development and refinement of the M_s - m_b discriminant as well as several other discrimination techniques. Since the near-field accelerograms can be used to decipher fine details of the pattern of the earthquake energy release in time and space (Trifunac and Brune, 1970; Trifunac, 1972a, b; Trifunac, 1974; Trifunac and Udawadia; 1974), we feel that this is a unique opportunity to fully exploit the existing information in the strong-motion accelerograms already recorded. To this end we are at present actively engaged in processing numerous strong-motion accelerograms and analyzing several of them that appear to be the most significant from the discrimination point of view.

TABLE I
BEAR VALLEY EARTHQUAKES, 1974

Station	Time				S-T (sec)	Amplitude (peak-to-peak in mm)		
						<u>L</u>	<u>V</u>	<u>T</u>
ECN	187 days	4 hours	3 min	57.3 sec	0.9	1	<1	1
	216 days	17 hours	33 min	26.1 sec	1.0	1.3	<1	1.3
GCR	187 days	4 hours	3 min	59.7 sec		<1	<1	<1
MLR	187 days	4 hours	3 min	57.7 sec	1.45	3	1	2.5
SMR	187 days	4 hours	3 min	57.9 sec		1.1	1.1	1.3
UBR	238 days	2 hours	24 min	32.9 sec	1.5	1.2	1	1
	332 days	23 hours	1 min	45.9 sec		<1	<1	<1
WBR	187 days	4 hours	3 min	57.1 sec	1.1	1	1	1.1
	270 days	15 hours	3 min	8.6 sec	0.9	2.2	<1	1.5
WKR	238 days	2 hours	24 min	32.9 sec		1.2	1	1
WMR	216 days	15 hours	3 min	51.3 sec		<1	<1	<1
	One record with no time					<1	<1	<1
WMV	216 days	17 hours	33 min	27.8 sec		1	1	1

We have examined the three-dimensional dislocation model described by Haskell (1969) as a possible basis for modeling the earthquake fracture process. Using the data from five strong-motion stations surrounding the fault zone of the San Fernando, California, Earthquake of February 9, 1971 (Figure it has been possible to find a model (Figure 5) which approximately correlates with the recorded ground displacements during the earthquake (strong-motion data, Figure 6) with the static deformations after the earthquake (geodetic data, Figure 7) and with the observed faulting in the San Fernando Tujunga area.

Finding the dislocation model for a given earthquake from strong-motion data is a difficult task involving the solution of an inverse problem which has no unique solution. The problem is further complicated by the effects of non-homogeneous media between the source and the receiver. It appears, however, that by recording the ground motion at distances less than one source dimension, it may be possible to derive a simple approximate source model that can satisfy the dynamic and static measurements of the earthquake effects in the low frequency band from D.C. to about 1 cps. For this frequency band the amplitudes of recorded waves are believed not to be affected seriously by the local geologic conditions.

In our continuing effort to extend this approach to smaller magnitude earthquakes, we studied the Parkfield, California, Earthquake of 1966 and found that detailed interpretation of the recorded ground motions is possible when three-dimensional Haskell's representation is used (Trifunac and Udawadia, 1974). Our future work will be devoted to an extension of this technique to smaller magnitude shocks.

DISLOCATION AMPLITUDES ON THE SAN FERNANDO FAULT EARTHQUAKE OF FEBRUARY 9, 1971

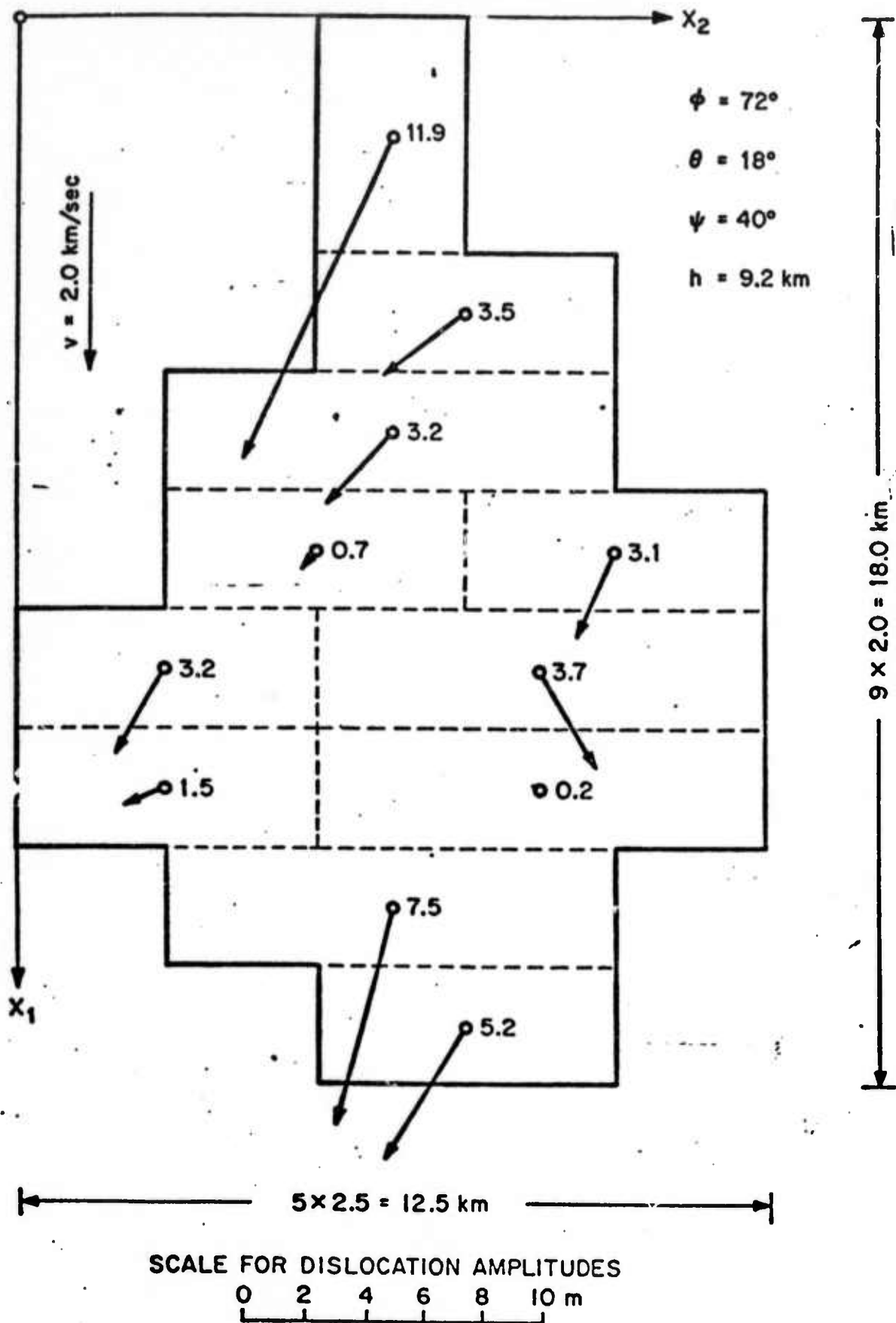


Figure 5

HIGH-PASS FILTERED GROUND DISPLACEMENTS DURING THE SAN FERNANDO, CALIFORNIA, EARTHQUAKE OF FEBRUARY 9, 1971

MEASURED — CALCULATED

($f_T = 0.10$ CPS, $f_C = 0.12$ CPS)

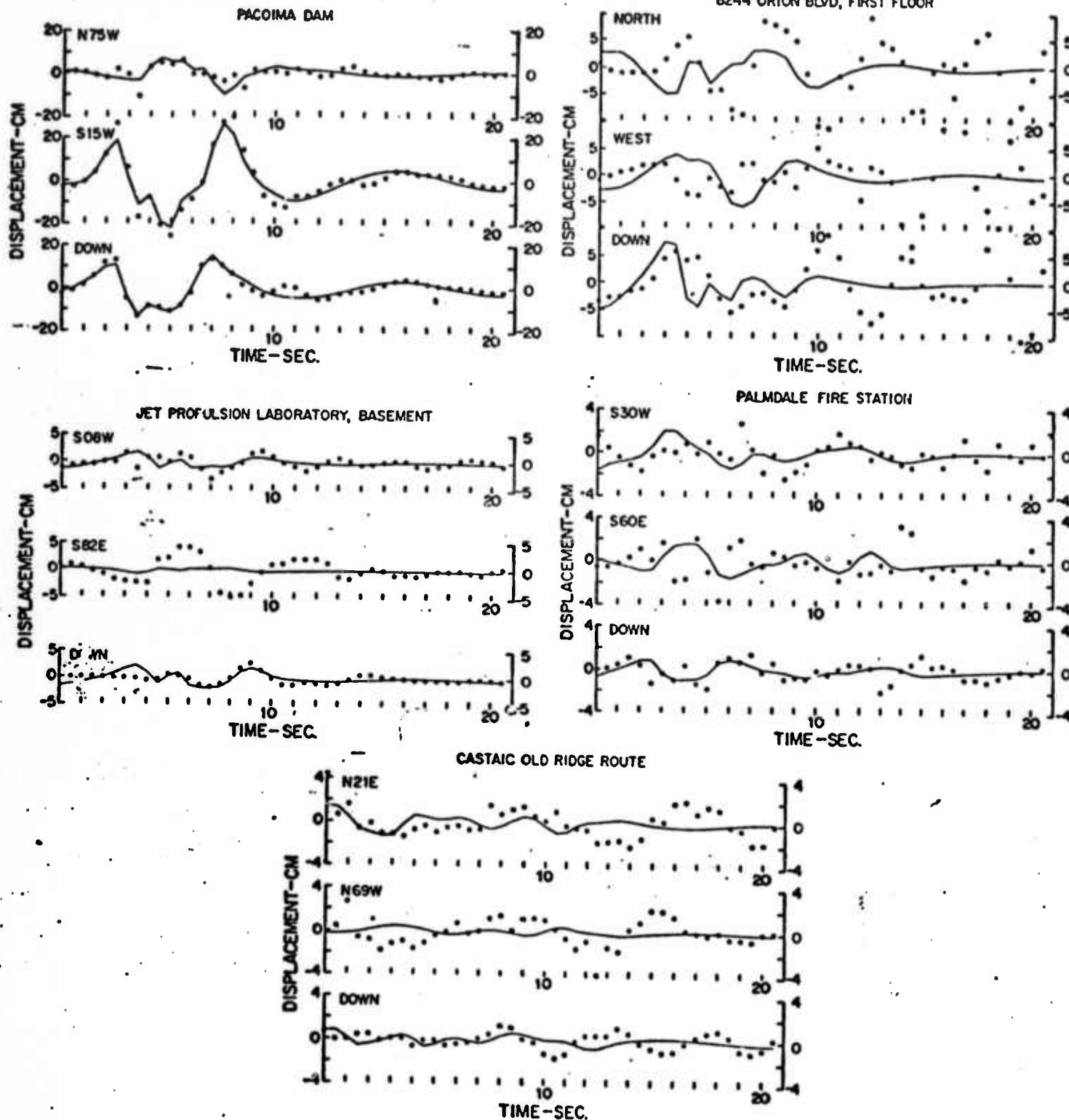


Figure 6

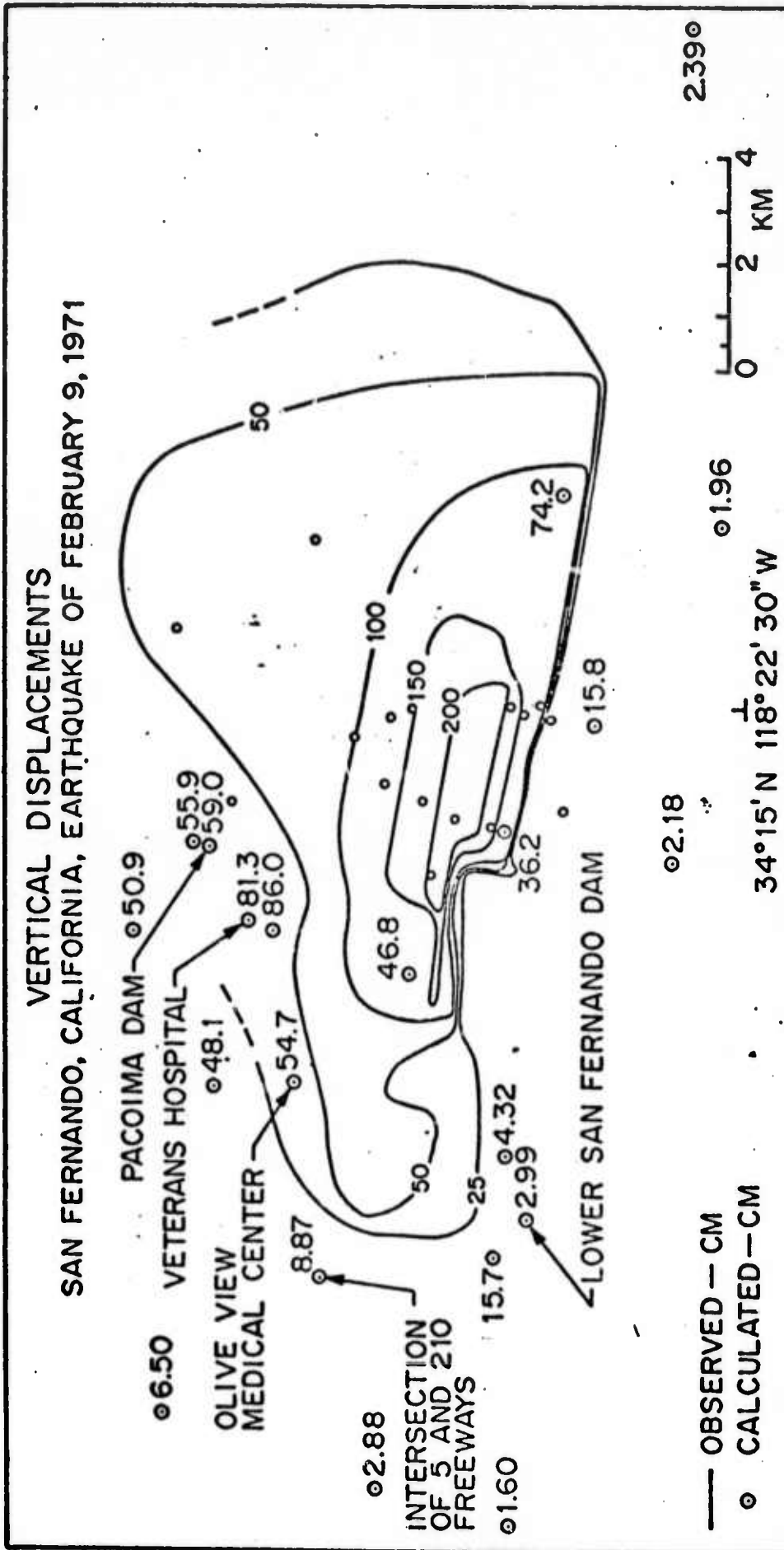


Figure 7

The Bear Valley, California, Earthquake of June 22, 1973 provided the first such opportunity. The magnitude of the shock was reported as $M = 3.9$, which is close to the threshold level below which it is quite difficult to record accurately strong-ground motion with conventional accelerographs. Nevertheless we obtained ten excellent accelerograms (Dielman, et al., 1975). Five stations that surround the epicenter have been selected for further three-dimensional dislocation studies. Preliminary results have indicated that it may be possible to match the recorded with the synthetic near field and body wave contributions quite accurately. Figure 8 shows an example of a good fit at station no. 1 (Fig. 4), which is located in the basement rock southwest of the epicenter. The quality of fit is not so good for stations no. 3 and no. 4 because these stations are located on the sedimentary deposits which filter the incident motions appreciably.

To see how the approximate solution, least square fitted to the observed data, agrees with the exact dislocation model we have to wait until such time as when it will be possible to measure dislocation amplitudes at the fault itself. The present analysis shows, however, that until that time comes it is worthwhile to (1) develop the representation of the dynamic dislocation models in non-homogeneous half-space and (2) deploy arrays of strong-motion accelerographs to measure the near-field strong ground motion. The results of this preliminary analysis already indicate the possibility of deciphering the details of the complicated dislocation processes and demonstrate how valuable the near-field strong-motion data are for acquiring an understanding

1

S 50° E



0.1 cm

N 40° E



DOWN

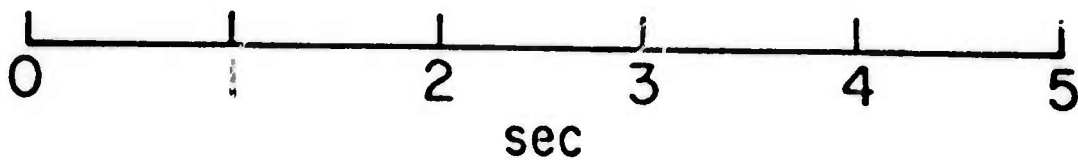


Figure 8

of earthquake source mechanism, of prediction of strong ground shaking for earthquake engineering purposes and for the development of sensitive techniques for discrimination between explosive and tectonic sources.

Under Caltech's subcontract (#28-88797C), Dr. Max Wyss of CIRES and the University of Colorado, investigated the possible improvements in the derivation of the source parameters from S-waves. To derive the S-wave source-spectrum a clean S recording is needed. This, however, is in general not available. On records near the source the S-phase is immediately followed by surface waves (Love and Rayleigh). At larger distances the S-pulse is followed by S coupled PL waves. These are a type of surface wave generated near the receiver. The problem studied in this work was to determine the difference between PL contaminated and uncontaminated S time series and spectra, as well as the difference in the source dimension and moment estimated from the spectra.

It was found by Dr. Wyss that the PL contaminated SV results deviate by approximately 30 percent from the P and SH results. In addition, the source dimension, r , and the seismic moment, M_0 , estimates from SV have a larger RMS error and suffer more from subjective interpretation of the spectra. M_0 and r estimates based on EW or NS components alone would be afflicted by subjectiveness and errors equal or somewhat less than those in the case of estimates based on SV.

The results of this work were presented at the National Meeting of the Seismological Society in Golden, Colorado, May 1973.

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